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POPULATION POLYGONS OF TEKTITE SPECIFIC GRAVITY FOR VARIOUS LOCALITIES IN AUSTRALASIA*

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ABSTRACT

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Measurements of specific gravity by the method of liquid floatation have been made on about 6,000 tektites from 18 different localities in Australasia, from 1 locality in Texas, and 2 in Czechoslovakia. Comparison of specific-gravity population polygons for various localities has led to the unanticipated conclusion that the australite population in southwest Australia is essentially the same as the philippinite population, rather than the population elsewhere in Australia. The javanite population appears closely related to certain populations in Australia. In several localities the presence of two superimposed populations is demonstrated. The specific-gravity evidence indicates that the Australasian tektites represent a single event comprising many distinguishable clusters, some of which have partially overlapped.

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INTRODUCTION

At the turn of this century, the Austrian geologist F. E. Suess (1900) gave the collective name of "tektites" to three widely separated groups of natural glass objects then known to be scattered over parts of Australia, Czechoslovakia, and the island of Billiton. In the intervening decades, multitudes of tektites also have been discovered in numerous other areas: in southeast Asia, the Philippines, and Indonesia, as well as on the continents of North America and Africa. This gradual revelation that tektites are widely spread has been accompanied by a most curious circumstance. Less difference sometimes is revealed between chemical analyses of two tektites found in different countries several thousand kilometers apart than between two tektites found in the same country only a few kilometers apart. Such circumstances have complicated the problem of ascertaining which of the widely dispersed tektite groups originate from the same event and which originate from different events.

During a field trip in 1962 to the major tektite collections around the world, two of us (DRC and HKL) routinely made measurements of the density of numerous tektites at each locality visited. The specific gravity of a total of 3600 specimens representing 14 different Australasian tektite localities were determined systematically during this trip. Subsequent analysis revealed some interesting patterns interconnecting certain of these tektite groups, and some tantalizing gaps in these patterns. In an effort to fill some of the gaps, additional measurements were made in the laboratory on about 2400 tektites, including specimens from four additional Australasian sites as well as sites from Texas and Czechoslovakia. These latter specimens were obtained on loan from various museums and collectors listed subsequently. Thus, the total number of specimens measured is about 6000, and the total number of localities 21.

The chemical similarities between various Australasian tektites are quite remarkable, as emphasized in the recent paper of Schnetzler and Pinson (1963). The familylike chemistry of Australasian tektites fortunately is such that an accurate measurement of the specific gravity provides a good measure of the distribution of at least the three principal chemical elements, Si, Al, Fe. An increase in density, for example, is accompanied by a linear decrease in Si, and a corresponding linear increase in Al, and Fe, and the alkalies (Barnes 1939, Chao 1963b). When a large number of specimens is considered, the presence of internal bubble cavities introduces some scatter in the correlated data of major element chemistry versus bulk specific gravity, but does not upset the general correlation. It does not follow, however, that the tektite population at two different localities necessarily would be the same if their average density were the same for one locality may comprise a relatively homogeneous cluster with a narrow range of specific gravity, while the other a very heterogeneous cluster with a wide range, but with the same average value. If, however, the population polygons is the same at two localities, this means that the entire spectrum of number distribution within each band range of specific gravity is the same; hence, the specific-gravity populations would be the same and the statistical distribution of major element chemistry would be expected to be essentially the same.

As emphasized by Chao (1963b), tektites were formed by a rapid mixing of materials: the turmoil of internal striae, the wide compositional variations between different glass inclusions, the iron-nickel spherule inclusions, and certain glass inclusions indicating splatter during penetration, all point toward a picture of tektite formation by violent mixing of more than one type of parent material during an impact process. A population polygon, therefore, is regarded as a reflection of the statistical intricacies of this natural mixing process insofar as concerns the principal rock or mineral components being mixed. Variations in minor chemical

components, of course, could not be detected in a population polygon because of their small effect on specific gravity.

The most compelling evidence to date for associating the Australasian tektites as a unit has been provided by potassium-argon age determinations. The results of such measurements have been given by Reynolds (1960), Gentner and Zähringer (1960), and, most recently by Zähringer (1963). In spite of some differences between the numerical values obtained for tektite age in these investigations, it is nevertheless certain that there are at least three distinct age groups: an old group in the United States, a middle-aged group in Czechoslovakia, and a relatively young group in Australia, Indonesia, southwest Asia, South China, the Philippines, and the Ivory Coast of Africa. The precise subgroupings, if any, of the young tektites are not entirely clear. Thus, the most recent K-A measurements of Zähringer suggest to him that the young tektites may, in turn, comprise two separate divisions: an Ivory Coast group (1.3 million years) and an Australasian group (0.7 million years). The K-A age may provide only an upper limit on the age of formation since degassing might not have been 100 percent complete for all tektites during their formation.

The uncertainty in geological age datings of tektites does not enable fine distinctions to be made between Australasian tektite groups. Barnes (1961) has expressed his opinion that the Australasian group itself comprises three or four different events, each of a different geological age. On the other hand, the geological observation of Chao (1963a) indicate to him that the Australasian tektites possibly are of a single age. It is clear that additional observations are desirable to help resolve existing uncertainties about the ages and groupings of tektites. The principal objective of this investigation is to provide new observational data pertaining to the question of whether the Australasian tektites represent a single or multiple events.

The present investigation encompasses observations on tektites from numerous museum and personal collections in various countries around the globe, and would not have been possible without the close cooperation of many individuals and institutions. It is a pleasure to acknowledge our indebtedness to these people. In the chronological order in which the field trip and the subsequent laboratory measurements were made, we wish to thank

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We are grateful to these people for their cooperation in providing the numerous tektite specimens for the measurements presented in this paper.

EXPERIMENTAL METHOD AND INTERPRETATION OF MEASUREMENTS

Method

The salient feature of the method employed for specific gravity measurement is that it is especially suitable for making precise relative comparisons between various tektite groups. All measurements were made with one instrument and a single technique, namely that of liquid floatation. This technique provides a high precision essentially independent of the tektite mass. The same balance weights, floatation weights, supporting platinum wire, and nulling counterweight were employed throughout all measurements of this investigation, both in the field abroad and in our laboratory. Crystals of zinc-iodide were dissolved in tap water and titrated to provide a liquid of density variable in small increments anywhere from 2.6, in which all tektites floated, down to 1.0, in which all sank. By successively immersing each tektite in solutions of incrementally increasing concentration of the zinc-iodide (the density of which is measured at each change) until the specimen changed from a sinker to a floater, the specific gravity of each tektite was determined to fall within certain narrow limits. The floatation technique is sufficiently sensitive that variation of ±0.001 gm/cm^3 can readily change a floater to a sinker, or vice versa, and the balance employed for measuring the liquid density is sufficiently sensitive that variations of ±0.0003 are

readily measured. Hence, for comparison purposes the relative accuracy is about ±0.001. Due to systematic errors, the absolute accuracy would not be as great (being about ±0.003 as determined from calibration by a precision-ground glass sphere of known mass and known diameter); but absolute accuracy is not relevant to our objective of making sensitive relative comparisons--with the same instrument--between the population polygons of tektites from different areas.

The population spectrum of tektite specific gravity at each locality was determined basically as a histogram, but is characterized herein by a normalized population polygon. In most cases, the density of several hundred tektites was measured for each locality; in all cases the number of specimens having density between regular band-width increments of 0.01 gm/cm^3 were determined, and this number divided by the total for the locality yielded the percentage of specimens falling within each 0.01 incremental range. The data uniformly are plotted as a function of density in such a manner that the ordinate of a point plotted at a density of 2.415, for example, represents the percent of the total population having density within the 0.01 range between 2.410 and 2.420, while that plotted at 2.425 represents the percent falling between 2.420 and 2.430, etc. It was also found that the correct incremental density range corresponding to the mode, and a reasonable measure of the percentage corresponding to modal density, could be determined with fair accuracy from as little as 30 specimens randomly selected in areas where the polygon of specific gravity happens to correspond to a relatively uniform population.

Population Polygons as Reflections of Variations in Chemistry rather than Cavities

A change in tektite specific gravity can be produced by variations either in chemistry or in internal bubble cavities. A population polygon reflects the combined effect of both variations. It has been found that for almost all tektite

groups, however, variations in chemistry dominate those of cavities in determining the shape of a polygon. Baker and Forester (1943) came to this conclusion from their studies of australite specific gravity. We have come to the same conclusion from study of other Australasian tektites, with few exceptions, for the reasons outlined in the remainder of this section.

Sizable cavities appear as irregularities at the lower end of the density range of a given population polygon. This low range corresponds to a relatively small percent of the total sample, as will be seen. In order to estimate the relative number of tektites containing cavities sufficient in number and size to affect the normalized population polygon, 10 to 20 thin sections about 1 mm thick were sliced from a suite of specimens encompassing the entire density range encountered in each of the localities SA1 (Thailand), P1 (Philippines), and I1 (Java). From observations in transmitted light, an obviously solid portion without bubbles was selected from each slice so that its true glass density could be measured. In this way the minimum glass density, ρ_{min}, was determined at each of these localities. Specimens with bulk density ρ_B less than ρ_m would indicate the presence of sizable internal cavities, rather than an unusually low glass density. The relative number of specimens with $\rho_B < \rho_{min}$ can be determined from the population polygon. The results are as follows:

Locality	ρ_{min}, gm/cm^3	Percent of specimens with $\rho_B < \rho_{min}$
SA1, Thailand	2.399	4.1
P1, Philippines	2.422	5.6
I1, Java	2.378	.8

In a large sample of tektites from a given locality, the presence of only 5 percent, or less, with $\rho_B < \rho_{min}$ would not affect the population polygon by a

significant amount compared to the much larger amounts by which the population polygons differ among different tektite localities.

From independent observations, it has been deduced that these circumstances also apply to the australites. In the collection of Dr. George Baker (locality A7a) a count was made of the number of fragment specimens exhibiting sizable bubble cavities visible to the unaided eye on the fractured surface, relative to the number not exhibiting such cavities. (Microscopic vesicles do not affect appreciably the bulk specific gravity, so these need not be considered.) About 4 percent of these fragments exhibited such cavities; a percentage of the same order as deduced above for the northern localities of the Australasian strewnfield. Consequently, it is to be expected that variations in internal cavities within tektites can have only a minor influence on the shape of the population polygon relative to the chemical variations in silica, alumina, and iron; and a comparison between two population polygons is interpreted primarily as a comparison between the statistical variations in chemistry between two tektite clusters.

One exception to these circumstances is represented by a certain class of tektites from Manila Bay. Here a "frothy" type of specimen of irregular shape is found among the normal rizalites. This type comprises about 15 percent of the total population (Beyer 1961-1962) and, if included in the population polygon, would broaden considerably the lower range of bulk specific gravity while lowering by somewhat less than 15 percent the polygon ordinates over the remaining range of specific gravity. This frothy type later is treated separately as a component population with its own population polygon reflecting variations in bubble cavities more than variations in chemistry. It is possible that the large chunky (or Muong Nong type) tektites found in southeast Asia, and the small core type tektites found in Java, may constitute additional exceptions analogous to the frothy variety found near Manila, but we have not investigated this point.

RESULTS

Table I lists the locality, the number of specimens investigated for each locality, and the location (collector, or museum) of the various tektites for which results are presented herein. The geographic location of each number locality within the Australasian strewnfield is shown on a map in figure 1. Locality identification is by a number following a lettered suffix wherein A = Australia, I = Indonesia, P = Philippines, SA = southeast Asia, and T = Texas.

Population Polygons for Nearby Sites

It has been found that some of the tektite areas encompass two or more localities each of which has a population polygon that cannot be distinguished, within our experimental uncertainty, from the polygon of other localities within the area. An example is illustrated in figure 2 wherein normalized population polygons of specific gravity are compared for four different localities P1, P2, P3, and P4 situated within a radius of several tens of kilometers around the area of Manila Bay. The observed differences between these population polygons are of the same magnitude as the possible experimental error and the statistical uncertainty involved with samples of the order of 100 specimens per locality. If the density of the ZnI solution were in error by 0.001 gm/cm^3 near the modal density, and, for example, were really 2.439 instead of 2.440, then the band width of true density interval for modal density would have been 0.011 instead of 0.01; and the number of specimens assigned to the 2.44-2.45 increment would be the order of 10 percent too high. Differences in population polygons of this order of magnitude, as will be seen subsequently, are far smaller than the differences between the population polygons for various localities situated several hundred kilometers apart. In general, the population polygons for localities separated by less than about 100 km could not be mutually distinguished, and such localities are lumped together to

represent one tektite area. Thus, the data from the four localities P1, P2, P3, and P4 have been combined in subsequent plots to form a single polygon representing the population for the Manila Bay area. As noted earlier, the near congruency of specific-gravity population polygons implies that the major chemical element distribution also is essentially the same, and that the various sites around Manila Bay correspond to portions of the same cluster. Previously, Schnetzler and Pinson (1963) found the chemical analyses of tektites from two different localities around Manila Bay (Pugad Babuy and Santa Mesa) to be so similar as to indicate origin from a common population. The population polygons of specific gravity corroborate this idea for all of the sites investigated in the Manila Bay area.

A different example illustrating the near congruency of population polygons for different Australian localities within an area around Kalgoorlie is illustrated in figure 3. The polygon for locality A1 represents specimens from Gindalbie and Broad Arrow (localities 40 km apart, and about 30 km and 70 km distant, respectively, from Kalgoorlie); this polygon differs by only a negligible amount from that for the Kalgoorlie locality A2a determined at the same time from 93 specimens in the West Australian Museum. The polygon for the Kalgoorlie area A2b represents 268 specimens from the Cook collection in the South Australian Museum, a collection which has been assembled from "Kalgoorlie and district", and represents a wider area around Kalgoorlie than that spanned by the distance between Kalgoorlie and either Broad Arrow or Gindalbie. The somewhat lower peak of the modal density for A2b might by expected in view of the wider area encompassed by this collection. In subsequent figures A1, A2a, and A2b are combined to yield a single polygon for the "Kalgoorlie area."

In many cases, several independent groups of tektites, varying in number of specimens per group, were selected from the same locality and measured separately.

From such observations it has been concluded that about 100 specimens are sufficient to characterize satisfactorily the essential features of the population polygon for a given locality. Some results illustrating the small dependence of population polygon or sample number, for sufficiently large samples, are presented in figure 4. Thus, the polygon for a sample of 104 specimens from the Nullarbor Plains (A3) would appear sufficient since it does not differ significantly from that for a much larger sample of 486 specimens; but a smaller sample of 44 specimens does differ significantly and is a statistically inadequate number in this case. By a "statistically inadequate number" is meant a sample sufficiently small that the difference between the polygon for it and other samples of this number is larger than the experimental error. As also illustrated in figure 4, the polygon for 248 specimens from Lake Wilson does not differ significantly from that for a different and larger sample of 738 specimens. Moreover, the 248 specimen sample was measured in the South Australian Museum by one coauthor while the 738 specimen sample was measured at the Ames Research Center by another, though with precisely the same instrument. In several other cases where comparisons could be made for a given locality, little difference was found either between samples of roughly 100 or of 200 specimens, or between samples measured independently by the three coauthors. All such differences were small compared to the differences between population polygons for different localities, such as the two Australian localities represented in figure 4.

Population Polygons for Czechoslovakian, North American, and Australian Tektites

The recent potassium-argon age determinations of Zähringer (1963) clearly demark the North American tektites (34 million years K-A age), Czechoslovakian tektites (15 million years K-A age), and Australian tektites (0.7 million years

K-A age) as at least three separate events. It is of interest then to compare representative population polygons from these three tektite showers, since, if the interpretation of tektite formation by a natural mixing process is correct, the polygons for separate events should be readily distinguishable. It is not to be expected that precisely the same proportions of component ingredients would be mixed during three separate impact events.

In figure 5 population polygons for Czechoslovakia and Texas are compared with that for southwest Victoria, Australia. Among the various Australasian localities investigated thus far, this particular one yields tektites with a modal density that is the lowest, and thus, the closest to the moldavites and bediasites. It is evident that the tektites in Czechoslovakia and Texas are characterized by greatly different population polygons than the Australasian tektites. This is to be expected in view of their known difference in major chemical make-up (principally a higher silica content).

As an incidental point it is noted that the two population polygons for Czechoslovakia indicate that the moldavites from Moravia have a lower average density, and hence higher average silica content, than those from Bohemia. The opposite trend was noticed by Cohen (1963) when he compared the chemical analysis of four specimens from each locality. This illustrates the precariousness inherent in any attempt to deduce statistical trends from only a few tektite specimens.

A population polygon for 366 tektites from locality A8 in southwest Victoria, previously has been determined by Baker (1956, fig. 8). His results yield a modal density between 2.40 and 2.41, with 20 percent falling within this 0.01 modal increment; our results (obtained on 78 specimens) yield the same modal value, with 22 percent falling in this increment. In fact, the two determinations agree well over the entire density range considering that two different methods of measurement were employed.

Population Polygons for Various Australasian Localities

The various Australasian localities are arbitrarily divided into three portions--northern, central, and southern--in order to limit the number of polygons superimposed in any one figure. The results are presented in figure 6 for the northern portion comprising southeast Asia and the Philippines; in figure 7 for the southern, or Australian, portion of the strewnfield; and in figure 8 for the central portion comprising the Indonesian localities of Java and Billiton. The Philippine localities are discussed first.

The closest agreement in figure 6 between any two polygons for the northern portion is that between Manila Bay (P1, P2, P3, P4, represented by cross symbols) and Anda (P6 represented by circle symbols). Anda, situated about 220 km to the northwest of Manila, obviously comprises portions of the same tektite population. Since the surface sculpture of the Anda tektites is characterized by rather bizarre patterns of V-grooves, in marked contrast to the more common rizalite patterns of circular pits and U-grooves, such differences must be due to factors other than different major-element chemistry, such as different geological etching conditions at the two localities coupled with possibly different stress and crack patterns within the glass.

The localities of Paracale (P5) and Santiago, Isabela (P8) also exhibit a mutually similar type of population polygon, though of quite a different nature than the Manila-Anda type. The Santiago-Paracale tektites are of greater average density than the Manila-Anda tektites. Santiago is about 300 km northwest of Paracale, along a line roughly parallel to the line connecting Manila and Anda. Again we would deduce that these two localities probably comprise a common population of tektite material, even though their shape types are categorically different: Paracale, near Coco Grove on the Bikol peninsula, is singularly noted for the large tektites (up to 1.07 kg) found on this peninsula, while Santiago, noted as

the locality for which iron-nickel spherules first were discovered in tektites, has produced only tektites of ordinary philippinite size. Both localities appear to contain a mixture of two component populations, a major component with modal density of 2.45+, and a minor one with modal density of 2.43+ or 2.44+. In a subsequent section, further discussion is presented of other localities for which the population polygons distinctly indicate that two or more component populations have been superimposed.

The sum total of measurements for the various Philippine localities appears sufficiently complete and consistent both to determine the direction of mean density gradient, and to provide evidence for the presence of a striplike distribution of tektites in this portion of the Australasian strewnfield. The mean density of the Busuanga (P7) tektites at the southwest is lower than that along the Manila-Anda line, which in turn, is lower than that along the Santiago-Paracale line to the northeast. Hence, it follows that the mean glass density increases in a direction pointing to the northeast. Of more significance, perhaps, is the fact that these data are in harmony with the idea of a northwest to southeast striplike distribution of the philippinites. From numerous observations of the geographical distribution of tektite finds in the Philippines, such an idea long ago was advanced by Beyer, and subsequently has been promulgated by him in several papers written during the past three decades (see Beyer 1961-1962, a compilation of his papers on tektites from 1928 to 1945). It is pertinent to note, however, that the evidence for such a distribution thus far is limited to the Philippines.

The population polygons determined for two localities in southeast Asia, shown by dashed lines in figure 6, are quite similar to those for the Philippines. In fact, the polygon for Dalat in the southeastern part of southeast Asia, is so close to that for Busuanga in the southwestern part of the Philippines, that these

two populations might be expected to represent separate portions of the same cluster. Further evidence for such a view is provided by the fact that at many of the localities in the Philippines a certain percentage of "Indochina type" or "Cambodian type" tektites is found. Such types are characterized by severely stretched and often contorted forms possessing bubble cavities that are elongated or tubular, rather than spherical as in the normal philippinites. In Australia, Java, and Billiton, these stretched and contorted forms are absent. In the Manila Bay region at the Santa Mesa site, the percentage of Indochina-Cambodian types is less than 1 percent (Beyer 1961-1962, Part II, p. 69), whereas at Busuanga, where the polygon is most similar to those in southeast Asia, it is 10 to 15 percent (ibid: p. 177). When we combine (i) the observed similarity in population polygons, (ii) the observations of Indochina tektite types in the Philippines in greatest abundance at that particular locality (Busuanga) where the philippinite polygon overlaps those from Indochina, and (iii) the evidence from K-A age determinations, which previously have indicated the radiogenic ages of these tektites to be the same, it must be expected that the southeast Asian and Philippine tektites are from closely related portions of one and the same event. Such circumstances might arise from a partial intermixing during travel through space, followed by near simultaneous landing on the ground of one extensive cluster; they might also arise, with due allowance for the earth's rotation, merely by a small overlapping of geographic landing patterns between two distinguishable clusters landing at somewhat different times (perhaps an hour or so apart), one primarily descending over southeast Asia, and the other primarily over the Philippines.

The population polygons for the southern portion of the Australasian strewnfield have led to a rather surprising conclusion. From the various polygons reproduced in figure 7, it is evident that the australites comprise two distinct types of population: (1) a relatively uniform type wherein approximately 50 percent of all tektites at a given area have a density within the 0.01-gm/cm^3 increment of

modal density; and (2) a relatively heterogeneous type wherein no more than about 20 percent fall within the modal increment. In contrast, all of the localities in the northern portion of Australasia, from Thailand through the Philippines, exhibit the relatively uniform type (see fig. 6); but for the southern portion, curiously enough, the relatively uniform type is found in the southwestern part of Australia at localities A1, A2, and A3, whereas the relatively heterogeneous type is found at the other Australian localities investigated (A4 through A9). The distinct delineation of two types of population in Australia was not expected; and even more unexpected was the result that the tektite population in southwest Australia is essentially the same as that in the Philippines. As may be seen from figure 7, the population polygon for Nullarbor Plains corresponds closely to that for Manila Bay. The polygon for Kalgoorlie also corresponds in modal density to that for Paracale although the noticeable secondary component (near 2.44 gm/cm^3) at Paracale is not present at Kalgoorlie. From the known congruences of shape and sculpture, and the known continuity of geographic distribution, the southwest australites long have been connected unquestionably to the same event as that which produced the australites in the rest of Australia; yet we now see that the tektites in southwest Australia--on the basis of congruence in specific-gravity population, and hence congruence in major-chemical-element population--are much more closely connected to the distant Philippine tektites than to their neighboring australite brethren. It is concluded that the australites and philippinites are from one and the same event.

When it first was relaized that the tektite population polygons for southwest Australia were in near congruency with those for the Philippines, two additional studies were embarked upon to obtain independent and more detailed observational data. First, the literature was searched for pertinent chemical analyses of tektites corresponding to these two particular areas; and, second, numerous specimens were obtained on loan from both areas so that their relative features of external

form and sculpture could be closely compared. Although these studies are discussed in a separate paper (Chapman 1963), it is noted here that the comparisons of chemical analyses, external form, and sculpture, alike show remarkably common characteristics between philippinites and the australites from the southwest portion of Australia. Such observations corroborate the deduction arrived at above from the observed similarity of population polygons.

Attention is now turned to the Indonesian tektite localities situated in the intermediate zone of the Australasian strewnfield. Thus far, data have been obtained from only two sites in this area: locality I1 at Sangiran, Java, and locality I2 on the island of Billiton. The polygon for Billiton is intermediate between the relatively homogeneous type prevalent in southeast Asia (fig. 6) and the relatively heterogeneous type prevalent in central, south, and southeast Australia (fig. 7), but resembles more closely the southeast Asian type population. The javanite population, situated only 600 km from Billiton, is markedly different. Moreover, the principal portion of the javanite population resembles much more australite populations over 3000 km distant (e.g., compare with Charlotte Waters, and Mulka) than the billitonite population. From their close proximity to Billiton, the javanites cannot logically be regarded as originating in an event separate from the billitonites; and, from the population polygons, the javanites cannot be clearly distinguished as separate from the australites. The inevitable conclusion from these measurements is that the javanites, billitonites and australites represent interrelated clusters of a single event.

Tektite Localities Containing Admixtures of Component Populations

In the course of conducting the measurements it was noticed that an over-all population sometimes could be separated clearly into separate subpopulations. For many localities, separate tabulations were made of the density of small tektites

versus large tektites, of elongated forms versus round forms, and of fragments versus complete forms; and in this way the presence of subpopulations was detected in certain localities.

The presence of two overlapping populations among the javanites was most apparent. One subtype comprises specimens which typically are small (about 1 centimeter or less in dimension), largely whole, crudely roundish, and readily identified--in cases where the specimen is essentially complete--by the presence of regular melt-flow patterns on one face (the front face ablated by aerodynamic heating during their entry flight as illustrated by Chapman, Larson, and Anderson (1962)). This type is a minority population in Java and is singular in comprising glass definitely of the highest density known among tektites. The maximum specific gravity recorded was 2.558 for one small specimen. (This specimen, donated to us by Dr. S. Sigit of the Geological Survey of Indonesia, has been given to Dr. E. C. T. Chao for chemical analysis.) In figure 8 the unusual "tail" on the javanite population polygon extending from about 2.48 to 2.56 gm/cm^3 is a manifestation of this minority population of high-density, small, ablated cores. In contrast, the majority population in Java, which arbitrarily is defined as all other javanites than the minority population, is characteristically less dense (2.38 to 2.48 gm/cm^3) and almost always the fragments are angular, termed "tektite waste" by von Koenigswald. This type of specimen is in the great majority, and includes a small fraction of fragments from the outer aerothermal stress shell of several millimeters thickness which invariably spall from large tektites (Chapman 1963). Photographs of the two types are presented in figure 9. Most javanites constitute the fragmental remnants of what once were relatively large glass objects before their plunge into the earth's atmosphere. These objects commonly were of dimensions the order of a man's fist, as judged from the surviving pieces of outer spallation shell; they fragmented in some cases during flight, and in other cases upon impact with the ground (von Koenigswald 1963; Chapman and Larson, 1963).

Some results from approximate determinations of normalized population polygons for the individual component populations at several localities are presented in figure 10. Here the component polygons for Sangiran and Charlotte Waters are compared. Inasmuch as the minority javanite population, identified as Java II, was determined from a limited number of specimens (38), its polygon is quite jagged and not highly accurate. In order to fill each 0.01 gm/cm^3 bandwidth increment with a statistically significant number of data points, a polygon which spans a wide range of density requires more specimens than one that spans a narrow range. Such jaggedness, which is therefore a reflection of an inadequate number of specimens, also is present among the philippinite minority populations presented subsequently. Even though such results are only approximate, the marked contrast between individual component populations is evident. In the case of Charlotte Waters the distinction observed between component populations was one of size only. The limited number of large cores investigated (28) all corresponded to component I of lower density, whereas medium lenses and small cores included component II of higher density, as well as component I.

An interesting circumstance evident from figure 10 is that the javanite I population and the Charlotte Waters I population are very similar. We find here a situation parallel to that emphasized earlier wherein it was pointed out that, insofar as specific gravity population is concerned, the southwestern australites are much more like the distant philippinites than they are like their neighboring australites. In the present case, it is noted that the javanite population is more like the distant population at Charlotte Waters than the nearby population at Billiton.

The tektites from Manila Bay have been classified by Beyer (1961-1962) into at least four groups: (I) normal rizalite types, (II) spongy type, (III) light colored - yellowish to greenish - relatively translucent type, and (IV) Indochina

or Cambodian type. Specimens from each of these types are illustrated in figure 11. Among a random sample of 155 specimens other than type I from the Ortigas site in Manila, 14 were found to be of the yellow-green type, and 6 of the Indochina, or stretched, type. From a count of 15,000 specimens in the Pugad Babuy collection, Beyer indicates that 15 percent of the total represent the type II spongy variety. From these various numbers a simple computation yields the following estimate of the over-all Manila Bay population: 83, 15, 1.5, and 0.7 percent, respectively, of types I, II, III, and IV. In figure 12, the spongy type II exhibits a broad polygon primarily because bubble cavities extend the bulk density into the range of lower values, and secondarily because this component also contains a small amount of material of density higher than that found in the more abundant type I rizalites. When results from chemical analyses of the various component types become available, much light undoubtedly will be shed on the interrelationships between the several component populations at a given locality, as well as between the various populations at different localities.

CONCLUDING REMARKS

On the basis of the present determinations of population polygons and of previous observations of tektite forms, a synoptic view of the Australasian tektite shower would be characterized by a complex pattern of many distinguishable clusters, some of which have overlapped in certain places. A complex rather than a simple pattern is envisioned inasmuch as in most areas sizable variations in tektite population are observed over distances of only several hundred kilometers--distnaces that represent a small fraction of the dimensions of the Australasian strewnfield; yet, in contradistinction, one case has been found for which the populations are essentially indistinguishable at opposite extremes of this strewnfield. Thus, the populations are clearly different between Santiago and Anda, 170 km apart; between Sangiran and Billiton, 600 km apart; and between Charlotte Waters and Mulka, 400

km apart; yet they are not really distinguishable between some localities in the Philippines and southwest Australia, some 5000 km apart. Under such circumstances the over-all distribution pattern of clusters appears to be too complex to delineate with any confidence at the present time. There are too many gaps, a thousand kilometers or so, between the various localities investigated to warrant interpolation in between when the distance scale of distinguishable variations in tektite population is only several hundred kilometers. One exception might be the Philippines, where the distance between any one of the localities investigated and another is no more than several hundred kilometers, and where the data are consistent with a localized pattern of mean density increasing in a northeast direction. But for the larger areas of southeast Asia, Indonesia, and Australia, many more measurements would have to be made in order to be certain that a realistic picture was obtained of the geographic distribution pattern of distinguishable clusters. Knowledge of this pattern undoubtedly would have an important bearing on the problem of pinpointing the place from which the tektites came.

The principal observational conclusions of this research may be summarized as follows: (1) that, insofar as population of specific gravity is concerned, the australites in southwest Australia are much more closely related to the relatively distant philippinites than to their neighboring australites; (2) that, analogously, most of the javanites appear more closely connected with certain distant australites than with the nearby billitonites; (3) that the populations in the Philippines and in southeast Asia appear smoothly contiguous, though mutually distinguishable; and (4) that in some areas two or more component populations can be separated from the admixture of tektites found at a given locality.

Our interpretation of these observations is that they corroborate the idea that all the Australasian tektites are from one event. The chain of reasoning is as follows: The australites in southwest Australia undoubtedly are from the same

event as those elsewhere in Australia, since there is geographic continuity in distribution, and in the quantitative ablation features, of the rare button forms from Kalgoorlie to Victoria. These forms are not found elsewhere in the world, and it is not to be expected that, as the earth spins and travels through space, such extraordinary products of some type of natural event always would zero in only on the southern portion of Australia, precisely matching in the process the landing pattern, the primary shapes and sizes, and especially the secondary aerodynamic ablation features. Hence, the australites in southwest Australia are from the same event as the other australites. But the specific gravity population of the southwest australites coincides with the philippinites, rather than with other australites; so the philippinites must be from the same event as the australites. Moreover, the southeast Asian tektite population is contiguous with the philippinites; hence, the southeast Asian tekties also formed during this event. Finally, the primary javanite population is essentially the same as certain australites; thus the javanites too are included in this commune of tektites. Consequently, in harmony with the previous measurements of a uniform K-A age for all Australasian tektites, it is deduced from entirely independent observations that the tektites now strewn from Australia to southeast Asia, from Thailand to the Philippines, represent a single event. Many millions of individual glass masses descended into the earth's atmosphere sometime in the distant past; but the date of this tremendous tektite shower has not yet been accurately established, nor has the true geographic limits of its extent, since the muds under the oceans dominating this part of the globe undoubtedly hide many millions more, perhaps even the major portion, of these remarkable glass objects.

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TABLE I.- TEKTITE LOCALITIES AND COLLECTIONS INVESTIGATION

SA = Southeast Asia
I = Indonesia
T = Texas
P = Philippines
A = Australia
C = Czechoslovakia

Locality number	Location of tektite find	Location of collection at time of measurement, and (number of specimens measured)
SA1	Northeast Thailand	a. Thai Lapidary (245) b. Ames Research Center (119)
SA2	Dalat, South Vietnam	a. American Meteorite Laboratory, Denver (195) b. Ames Research Center (12)
P1	Ortigas site, near Manila	a. U. S. Operations Mission, Manila (304) b. Ames Research Center (535) Type I - 270 fragments - 110 whole Type II - 135 Type III - 14 Type IV - 6
P2	Pugad Babuy, Bulacan	Beyer collection, Manila (106)
P3	Marulas, Bulacan	U. S. National Museum (98)
P4	Camarin, Novaliches, Bulacan	U. S. National Museum (97)
P5	Paracale, Bikol Peninsula	a. U. S. National Museum (50) b. U. S. Operations Mission, Manila (22)
P6	Anda	U. S. Operations Mission, Manila (127)

P7	Busuanga Island	Beyer collection, Manila (76)
P8	Santiago, Isabela	a. Beyer collection, Manila (241) b. U. S. National Museum (204)
I1	Sangiran, Java	a. Von Koenigswald Collection, Utrecht (117) b. Geological Survey of Indonesia, Bandung (258) c. Ames Research Center (39)
I2	Billiton Island	a. Rijksmuseum, Leiden (105) b. Geological Survey of Indonesia (19) c. Ames Research Center (5) d. U. S. National Museum (4)
A1	Gindalbie and Broad Arrow	Western Australian Museum (59)
A2	Kalgoorlie	a. Western Australian Museum (93) b. South Australian Museum, Cook collection (268)
A3	Nullarbor Plains	South Australian Museum, Shaw collection (486)
A4	Lake Wilson	a. South Australian Museum (248) b. Ames Research Center (738)
A5	Charlotte Waters	South Australian Museum, Kennett Collection (387)
A6	Mulka	National Museum of Victoria (259)
A7	Port Campbell	a. Baker collection, Melbourne (46) b. Melbourne University Geology Department (7) c. National Museum of Victoria (2)

A8	Stanhope's Bay	a. National Museum of Victoria (19) b. Ames Research Center (4)
A9	Uncertain locality in Australia or Tasmania	Melbourne University Geology Department (72)
T1	Lee County, Texas	U. S. National Museum (146)
C1	Habri (Bohemia), Czechoslovakia	U. S. Geological Survey, Washington, D. C. (108)
C2	Moravia, Czechoslovakia	U. S. Geological Survey, Washington, D. C. (37)

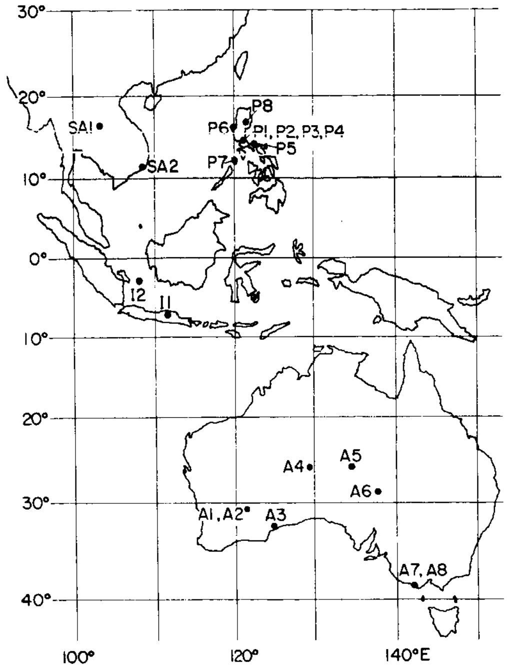

Figure 1.- Australasian localities investigated.

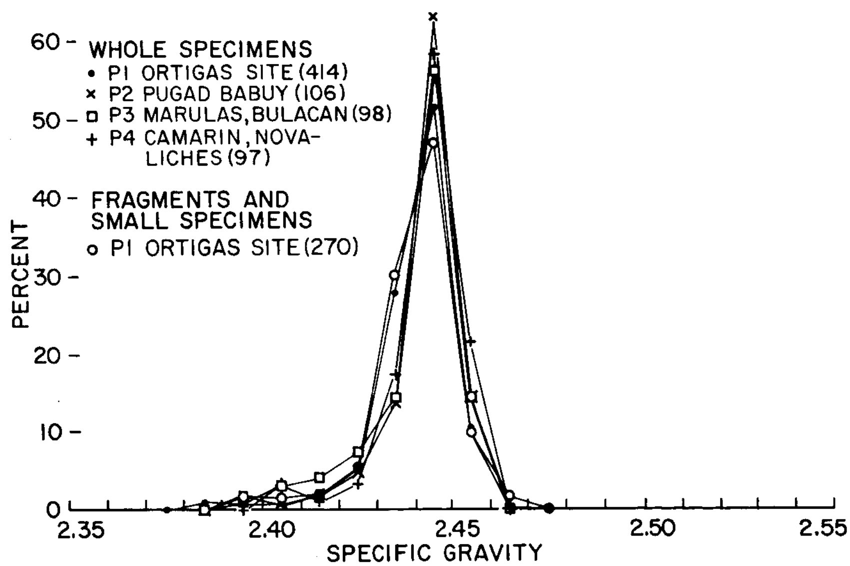

Figure 2.- Similarity of population polygons for various localities around Manila Bay.

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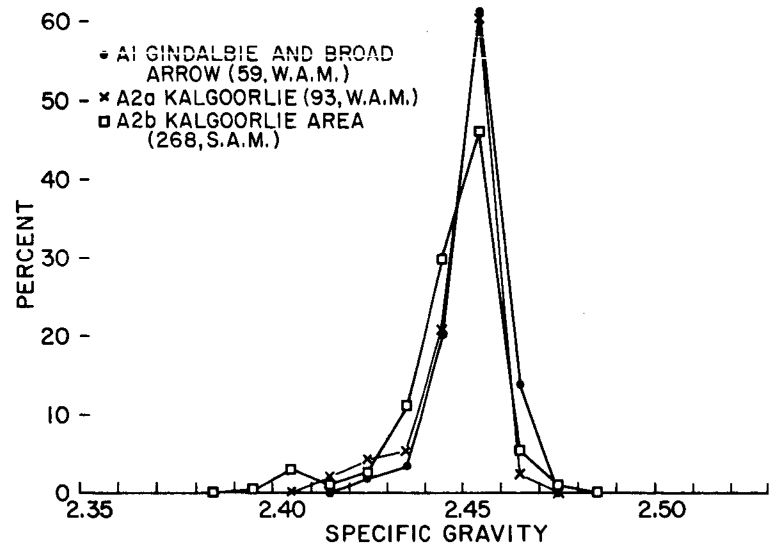

Figure 3.- Similarity of population polygons in Kalgoorlie area.

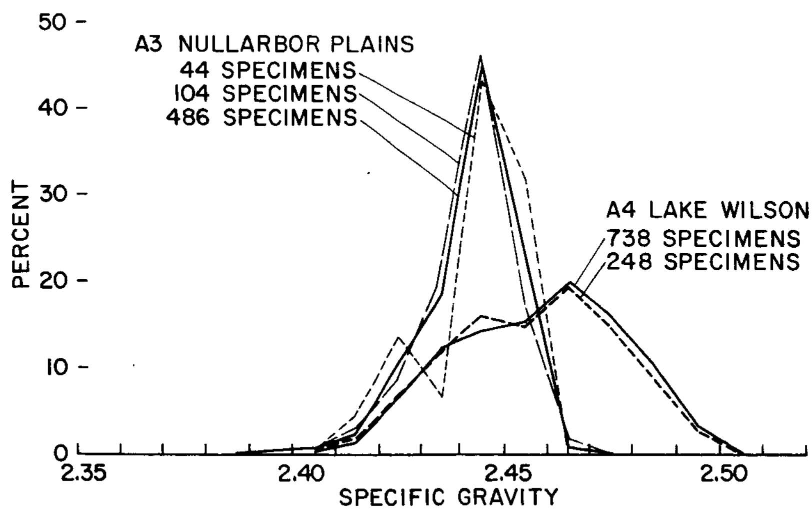

Figure 4.- Effect of sample number on population polygon.

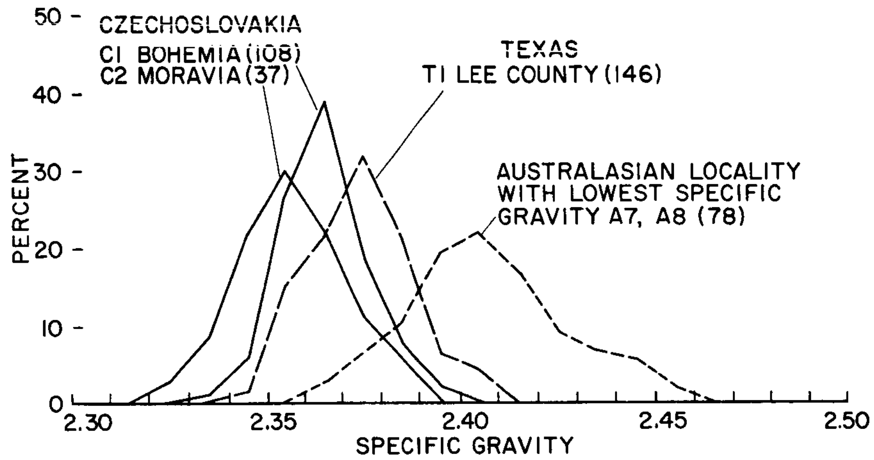

Figure 5.- Comparison of population polygons for two Czechoslovakian, one North American, and one Australasian locality.

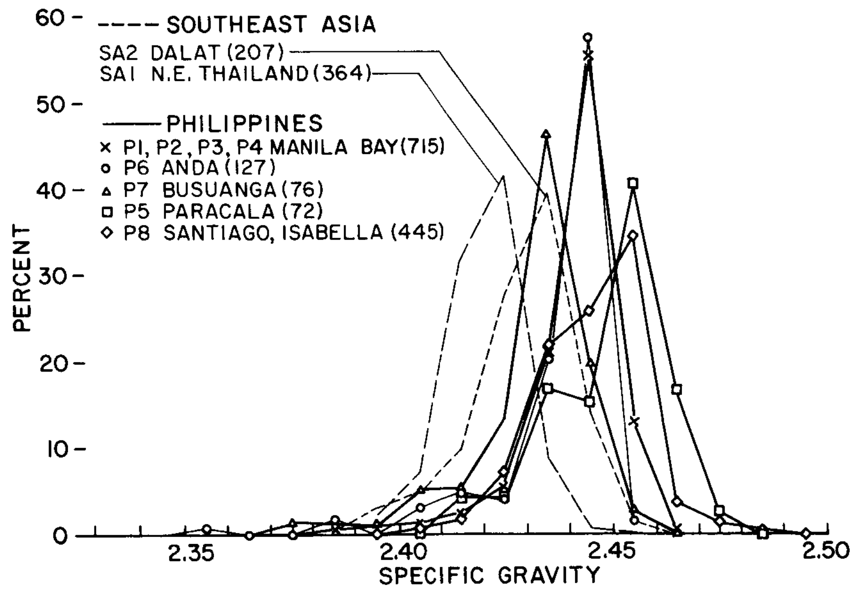

Figure 6.- Population polygons for localities in southeast Asia and the Philippines.

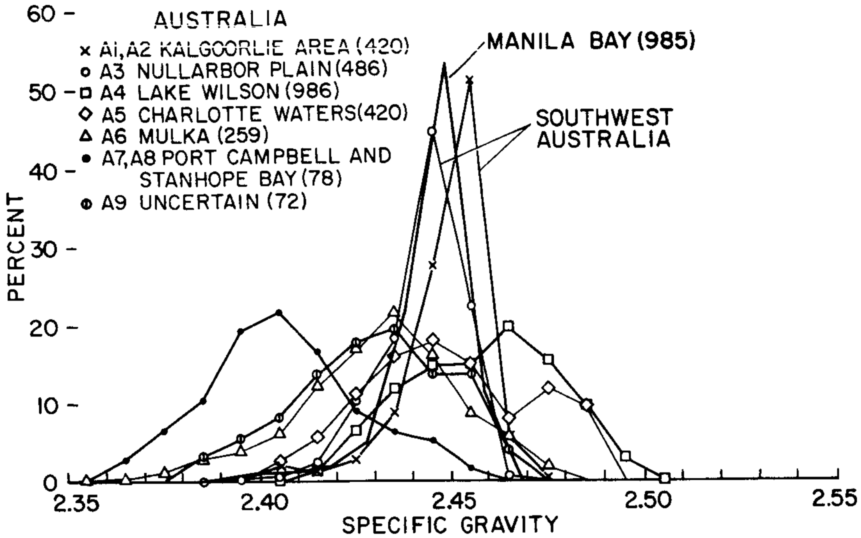

Figure 7.- Population polygons for localities in Australia and comparison with Manila Bay.

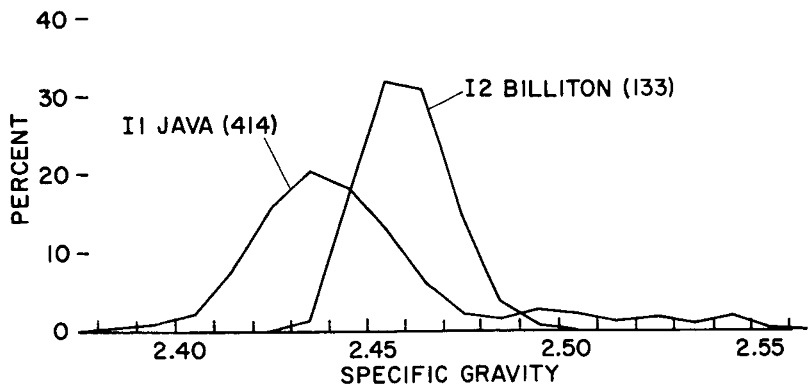

Figure 8.- Population polygons for localities in Indonesia.

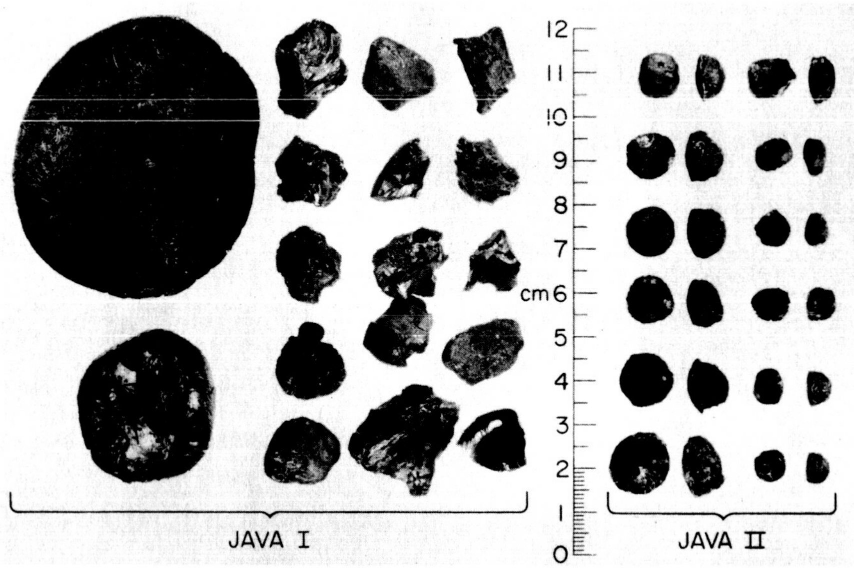

Figure 9.- Two component population at Sangiran, Java (tektites from collection of geological survey of Indonesia, Bandung, Java).

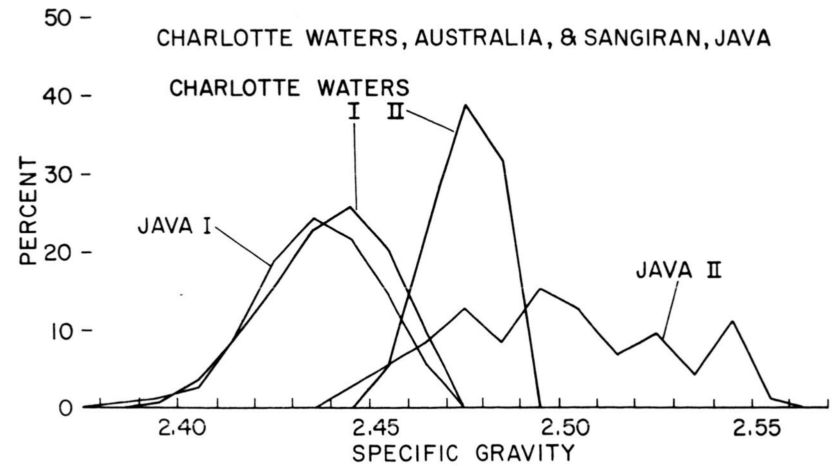

Figure 10.- Population polygons for component populations at Sangiran and Charlotte Waters.

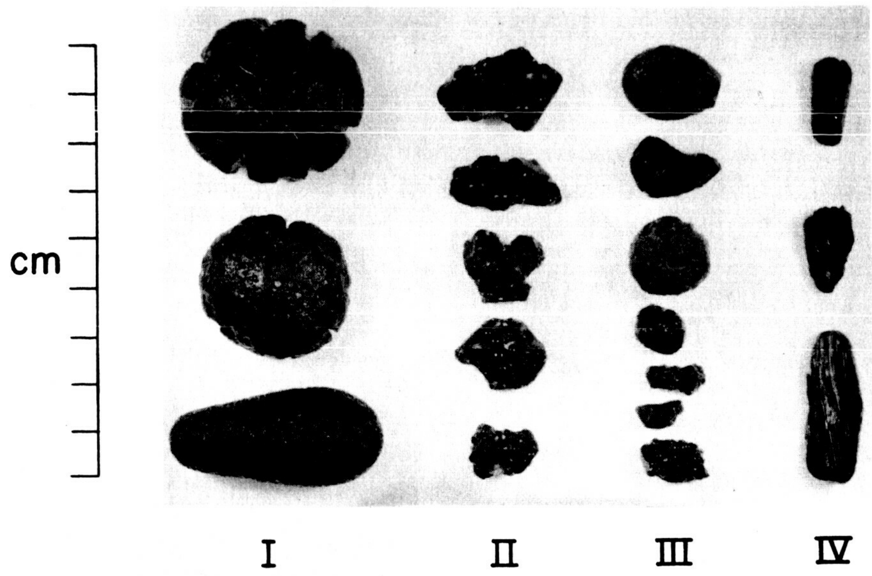

Figure 11.- Component populations of Manila Bay tektites.

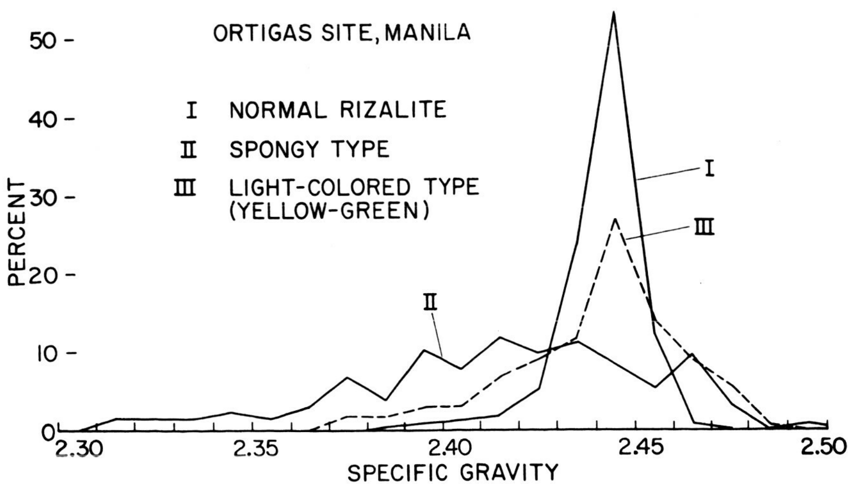

Figure 12.- Polygons for component populations at Ortigas site, Manila.